REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

2

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE 3/93

3. REPORT TYPE AND DATES COVERED TECHNICAL

4. TITLE AND SUBTITLE
NEAR REAL-TIME GIS IN DEEP-OCEAN EXPLORATION

5. FUNDING NUMBERS
ONR N00014-90-J-1848
ONR N00014-90-J-1912

6. AUTHOR(S)
JONATHAN C. HOWLAND, MARTIN MARRA, DANIEL F. POTTER AND W. KENNETH STEWART

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MA 02543

8. PERFORMING ORGANIZATION REPORT NUMBER
WHOI CONTR. 8046

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
OFFICE OF NAVAL RESEARCH
ENVIRONMENTAL SCIENCES DIRECTORATE
ARLINGTON, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
In citing this report in a bibliography, the reference given should be: PP. 428-435 IN PROCEEDINGS OF THE '92 ASPRS/ASCM/RT 92 CONVENTION. THE AMERICAN SOCIETY OF PHOTOGRAMMETRY AND REMOTE SENSING AND THE AMERICAN CONGRESS ON SURVEYING AND MAPPING

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

During a 1991 oceanographic research expedition to the Juan de Fuca Ridge, the Deep Submergence Laboratory (DSL) of the Woods Hole Oceanographic Institution (WHOI) applied interactive mapping with a geographic information system (GIS) in conjunction with real-time navigation. As DSL's remotely operated vehicle (ROV), *Jason*, surveyed a hydrothermal vent field, acoustic navigation updates were combined with maps generated to the specifications of participating scientists. The maps, which were generated in near-real time, were used to plan vehicle operations in a hazardous environment and to monitor survey progress and data quality.

Geologic observations made in real-time by scientists monitoring ROV sensors were logged into data files, combined with processed navigation, and used to produce preliminary updates to maps of the vent field. This experimental combination of GIS technology with navigation and visualization software was highly successful. Future scientific efforts will include further processing of sensor data, integration of image products into the GIS database, and the production of high-quality mapping products.

14. SUBJECT TERMS
1) GEOGRAPHIC INFORMATION SYSTEM
2) MAPPING
3) ROV

15. NUMBER OF PAGES 8

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

Near-Real-Time GIS in Deep-Ocean Exploration

Jonathan C. Howland
Martin Marra
Daniel F. Potter
W. Kenneth Stewart

Deep Submergence Laboratory
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Abstract

During a 1991 oceanographic research expedition to the Juan de Fuca Ridge, the Deep Submergence Laboratory (DSL) of the Woods Hole Oceanographic Institution (WHOI) applied interactive mapping with a geographic information system (GIS) in conjunction with real-time navigation. As DSL's remotely operated vehicle (ROV), *Jason*, surveyed a hydrothermal vent field, acoustic navigation updates were combined with maps generated to the specifications of participating scientists. The maps, which were generated in near-real time, were used to plan vehicle operations in a hazardous environment and to monitor survey progress and data quality.

Geologic observations made in real-time by scientists monitoring ROV sensors were logged into data files, combined with processed navigation, and used to produce preliminary updates to maps of the vent field. This experimental combination of GIS technology with navigation and visualization software was highly successful. Future scientific efforts will include further processing of sensor data, integration of image products into the GIS database, and the production of high-quality mapping products.

Introduction

The Woods Hole Oceanographic Institution's Deep Submergence Laboratory was founded in 1982 to develop unmanned, underwater vehicle technology and to apply such developments in scientific exploration of the oceans. In pursuing these goals, DSL has developed several underwater vehicles including *Jason/Medea*, a paired-vehicle system used in several undersea expeditions [Ballard et al., 1991]. DSL has also developed a family of optical and acoustic systems including a towed120-kHz swath-mapping sonar [Harris et al., 1985; Stewart, 1991a]. These vehicles share a common shipboard control system and are deployed together synergistically in multiscale, multisensor mapping efforts.

During the Summer of 1991, the Deep Submergence Laboratory, in conjunction with the University of Washington and the U.S. Navy, conducted such a multiscale, multisensor mapping effort on the Juan de Fuca Ridge, a region of active geologic faulting located

approximately 200 miles off the coast of Washington State and British Columbia. The site is characterized by hydrothermal venting and "black smokers," geologic structures that vent extremely hot water and dissolved particulates from the seabed into the water column.

As part of the effort to understand, visualize, and manage the massive amounts of data produced by these advanced mapping systems, we employ a variety of strategies, including GIS use [Stewart, 1991b]. On this cruise, DSL combined interactive GIS functions with near-real-time data to focus on two main goals: 1) to incorporate newly collected scientific data with previously mapped features in an interactive vehicle-position display, and 2) to allow easy, interactive analysis of new scientific observations within the context of historical data. This paper focuses on the methods used to approach these two goals.

Interactive Vehicle-Position Display

Data from DSL's underwater systems are collected, processed, and stored in a distributed computer network, shown in Fig. 1 as it existed during the Summer of 1991. Most of these systems were housed in a seagoing control van on the deck of the U.S. Navy's Deep Submergence Support Ship, *Laney Chouest*. Vehicle navigation was provided by two acoustic systems: low-frequency, long-baseline transponders and a high-frequency, short-range system [Hahn et al., 1985].

During field operations, data from the different sensors are transmitted over a token-ring network to a real-time logging computer for tape storage and to a system logger on Ethernet by way of a protocol router. Data records are stored in magnetic-disk files on the Unix-based system logger, where they can be accessed by any machine on the network. During the 1991 cruise this included a Unix workstation running the ARC/INFO GIS.

Attention during the 1991 cruise focused on the Endeavour vent field, situated on the Juan de Fuca Ridge about 2200 m below the sea surface. The site had been explored prior to the *Jason/Medea* efforts using large-scale mapping systems and direct observation from manned vehicles including WHOI's deep submersible, *Alvin*. A geologic base map, constructed from *Alvin* observations using manual techniques [Robigou et al., 1989], was digitized prior to the cruise to serve as the initial context for vehicle-position displays.

An interactive position display was considered essential by the participants in the *Jason* operations. The research area is laced with black smokers, which spew streams of sulphide-rich fluid into the sea at temperatures above 300 degrees C. If the vehicle or its fiber-optic umbilical cable were to pass through the hot emissions from an active vent, damage or loss of the system could occur. Entanglement of the umbilical with an inactive structure could also result in a serious situation.

Previous investigators at the site had also deployed long-term monitoring devices including moored current meters, temperature probes, scintillation meters, and other instruments. Certain of those sensors posed as much danger to the vehicle as did the geologic structures, particularly those deployed well up in the water column. Entanglement of *Jason's* tether in one of these moorings could have caused loss or damage to the ROV, its onboard sensors, or the moored device.

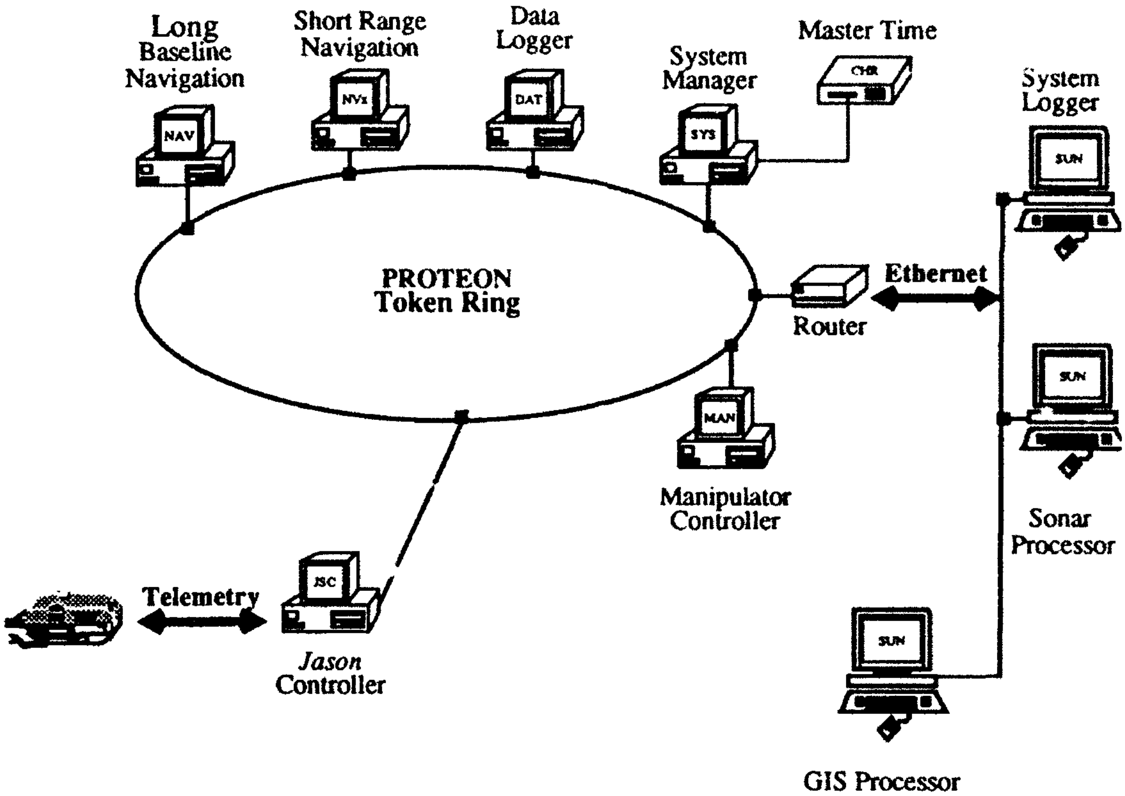

Figure 1. DSL Control and Data Network

Markers also left behind by earlier expeditions are less threatening but equally important These are boldly labelled in easy to read letters and numbers, providing visual references for manned submersible pilots and their scientific passengers. Under low-visibility conditions in complex terrain, the markers provided similar assistance to *Jason* pilots. Occasional visits to premapped markers offered confidence check-points for real-time navigation.

The scientists aboard *Laney Chouest* were able to provide a list of sensors and markers, along with positions, which were entered in the GIS. Using a combination of the basemap, sensors, and markers, scientists were able to plan and lay out survey lines on a workstation. These lines became a component of the GIS database and were incorporated in the interactive display. Of importance was that the interactive nature of the GIS and its ability to integrate all available data aided in this sometimes tedious survey task.

Following this planning stage, features representing sensors, markers, and survey lines were overlaid on the geologic base map to produce color navigation displays according to the scientists' specifications. A raster file was then saved to disk, a long with reference data about the origin and scale of the map coordinate system.

This raster map was subsequently displayed by Seaview, a custom DSL application. As real-time data were logged across the network, navigation fixes were immediately accessed and plotted on the basemap to show constantly updated vehicle position. Pre-

vious vehicle positions were indicated by green dots, which came to be known on the cruise as "bread-crumbs" because of their similarity to Hansel and Gretel's ephemeral trail. Figure 2 shows one such display from the expedition.

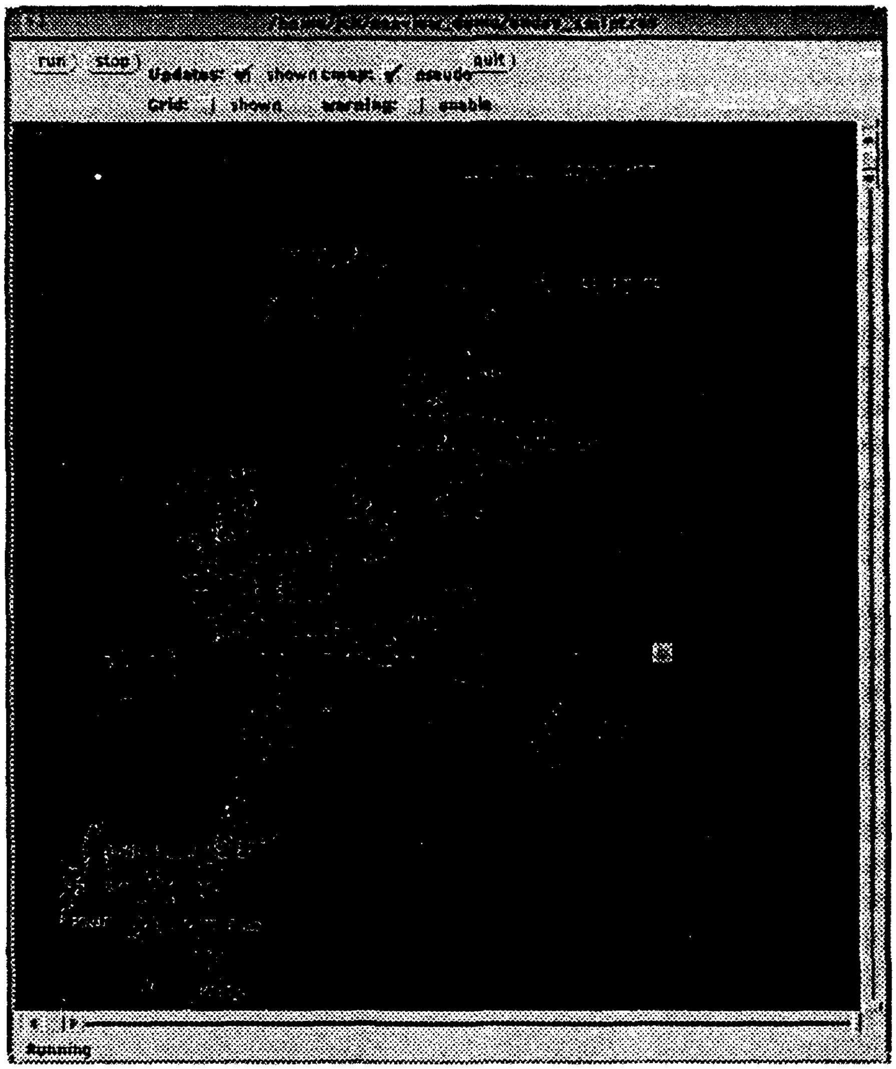

Figure 2. Sample Seaview Display

Using workstations on the Ethernet distributed around the ship, several Seaview sessions operated simultaneously with different basemaps but the same navigation file. Because Seaview is an X Window System application, it is available to multiple users with different CPU architectures. Aboard *Laney Chouest* Seaview was used for:

1) avoidance of hazardous areas in the vent field; scientists were able to safely direct an ROV pilot to areas of interest, avoiding dangers to the vehicle.

2) tactical planning; because the *Jason/Medea* vehicle pair moves quite slowly (usually less than 1.0 knots), vehicle operations must be planned to maximize the use of vehicle sensors and capabilities; by allowing the shipboard operators to effectively keep track

of vehicle position in the context of many different features of scientific interest, operations could be streamlined.

3) assessment of survey progress; with survey track lines displayed on the geologic base map, survey coverage could be measured at a glance.

Seaview was written as a generalized grid-display program. It does not depend upon the use of ARC/INFO for creation of the underlying raster file, although the GIS was extremely useful for this purpose during the 1991 cruise. Seaview was originally developed to work with raster files derived from a hull-mounted, multibeam sonar system and to display position data from DSL's towed sidescan sonar. However, the generality of the approach taken during Seaview's design and coding of makes it an effective multipurpose mapping tool.

Scientific Data Input

The second goal of GIS efforts during the 1991 cruise was to facilitate the recording and application of scientific data while still in the field. As the *Jason* vehicle maneuvered about the vent field, scientists in the control van were continuously making new geologic observations as they viewed the output from *Jason*'s sensors. This includes high-resolution video, electronic still camera imagery, and sidescan sonar data. Along with vehicle navigation and attitude data, these are displayed on a bank of large video monitors in the control van and provide the basis for real-time geologic interpretation.

As observations are made, scientists and research assistants sitting at the control van's system manager console (Fig. 1) key in new data; an event record is automatically generated, time stamped, and written immediately to tape for long-term storage. Paralleling the route for navigation and other vehicle data, a separate record is transmitted over the network to the system logger for additional processing.

At the completion of each segment of the survey, the navigation data from that segment are processed with custom filtering, smoothing, and conversion routines. Using tools developed at DSL, the smoothed navigation is merged with the scientific observation records to produce final records comprising position, time, and observation parameters. These records are then imported into the GIS to allow spatial query and analysis and to be combined with the previously mapped data (Fig. 3). The results of these analyses could be used not only for scientific purposes, but also for the production of new Seaview base maps that were fed back to the real-time displays

Lessons Learned

Among the several lessons from this expedition and previous field efforts is that the GIS can be a powerful tool for integrating and querying scientific data according to their spatial distribution, a key parameter of oceanographic research. If such data are properly navigated within a coherent geodetic framework they can be readily manipulated with a commercially available GIS, perhaps in a manner not originally envisioned by developers or users. DSL's application of the GIS to generate Seaview base maps offers an example.

One of the primary scientific products from the Juan de Fuca cruise, however, could not be adequately represented in a GIS. Equipped with sensors to measure conductivity, temperature, and depth, the *Jason* vehicle collected data in horizontal and vertical

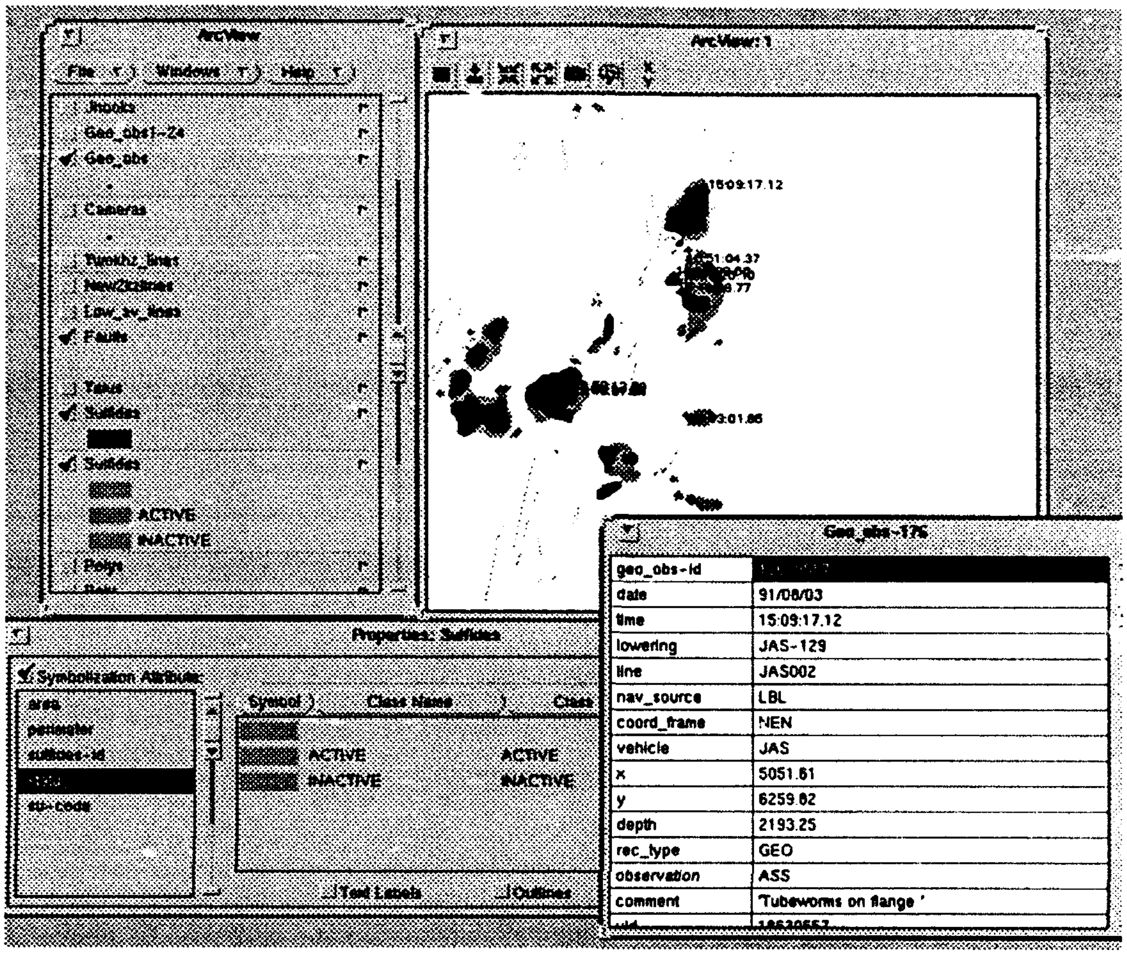

Figure 3. Post Survey Data Analysis

transects. Like many subsea data sets these are fully three dimensional, whereas current GIS technology is rooted in two dimensions. Although the systems may generate three-dimensional surfaces, these cannot be used to position or access volumetric data. Unless geographic information systems evolve to address such needs, their full potential for undersea applications will be restricted.

Problematic as well is the dimension of time. During field operations and later analysis, recorded time stamps provide the essential keys for processing then merging the many different streams of information with positional tags. The raw data are fundamentally time series (including navigation) and filtering or other signal processing must be carried out in the temporal domain. Coarse navigation data must also be interpolated for more precise location of discrete observations and other events. Such operations are best handled outside the GIS framework.

The final merger with navigation data is a geocoding or gridding process in which these time series are mapped to the spatial domain where GIS technology excels. As a component of the GIS database, time stamps can be useful for direct query or, when records are retrieved by spatial queries, as an index into other data sets not directly managed by

the GIS, for example, underwater video footage. As a primary key, however, time tags have limitations since uniqueness cannot be guaranteed in an application characterized by concurrent measurements and simultaneous events.

Finally, it is important that real-time information-management tools are designed to operate synergistically with the structured database schema. While free-form text can be accommodated, a taxonomy of specific record types and fields must be generated in advance for greatest efficiency and best results. DSL provides for this with programmable function keys on the system manager, with provision for additional comments at the end of each record. Although this text cannot be queried from within the GIS, it is frequently useful in scientific analysis and for keeping track of operational parameters.

Ongoing Development

DSL routinely collects many other data types that can be managed by a GIS. Digital sensor data, such as electronic still camera imagery, can also be tied to its geographic location using the same techniques applied to scientific observations. Rather than saturate on-line storage with volumes of image data, however, database records comprise descriptors that characterize image content with a pointer to its storage location, whether on-line or saved to archival media. Similar approaches are applied to sonar data for discrete features of interest and new programs under development will generate and maintain descriptors for localized target images.

Acoustic sensors, imaging and bathymetric sonars, also generate gridded maps and serve as the basis for subsea terrain classification. As this classification is carried out in a geographic context, the results will be available for many uses, including terrain-relative positioning, rapid geologic mapping, and refinement of acoustic models. In research stages as well, we are exploring the application of a GIS for interactively delimiting geologic provinces in training neural networks and for managing ground-truth data.

Complementing our focus on direct interaction with GIS data for scientific analysis are thrusts toward more real-time capability and expansion of the information-management process to encompass more data at sea. In the first case, this can lead to more on-site feedback and more efficient use of costly shipboard time; in the second an end-to-end approach to managing scientific data, starting at the source, can reduce typical postprocessing delays and enhance scientific productivity. Our relationship with GIS technology is evolving but we are confident of its sustained presence in our seagoing toolkit.

Acknowledgments

Researchers from the University of Washington, notably Veronique Robigou, are responsible for creation of the original geologic base map and for all onboard geologic interpretation and analysis. DSL's Steve Gegg contributed significantly to early development of the Laboratory's GIS capabilities and conducted at sea processing of navigation and other GIS data sources.

The original development of DSL's GIS and information-management techniques was made possible by a Mellon Grant from the Woods Hole Oceanographic Institution. Ongoing development has also been supported by the Office of Naval Research through grants N00014-90K-0070 and N00014-90-J-1848. Funding for the 1991 expedition was provided by ONR grant N00014-90-J-1912 and OP-23 contract N00014-89-D-0255. This is contribution 8046 of the Woods Hole Oceanographic Institution.

References

Ballard, R. D., D. R. Yoerger, W. K. Stewart, and A. Bowen, 1991, "ARGO/JASON: A Remotely Operated Survey and Sampling System for Full-Ocean Depth," in *Proceedings of the IEEE Oceans 91 Conference*, pp. 71-75.

Hahn, D. A., G.N. Williams, M. Wilcox, and P. Wilcox, 1985, "A Computerized High Resolution Underwater Ultrasound Triangulation Mapping System," in *Proceedings of the MTS/IEEE Oceans 85 Conference*, pp. 104-109.

Harris, S. E., R.H. Squires, and E.M. Bergeron,1987, "Underwater Imagery Using an Electronic Still Camera," in *Proceedings of the MTS/IEEE Oceans 87 Conference*, pp. 1242-1245.

Robigou V., J. R. Delaney, and R. E. McDuff, 1989, "Geology of the Endeavour Segment of the Juan de Fuca Ridge and its Associated Hydrothermal Fields," *EOS Transactions of the American Geophysical Union*, Vol. 70, No. 1, p.1161.

Stewart, W. K., 1991a,"High-Resolution Optical and Acoustic Remote Sensing for Underwater Exploration," *Oceanus*, Vol. 34, No. 1, pp. 10-22.

Stewart, W.K., 1991b,"Visualization Resources and Strategies for Remote Subsea Exploration," in *Scientific Visualization of Physical Phenomena*, Springer Verlag, Tokyo.